

## 6. Design Input—Equivalent Single Axle Loads

---

- 6.1. Introduction
- 6.2. Calculate the Load Factor for Each Vehicle Category
- 6.3. Calculate Design ESALs
- 6.4. Historical ESALs

### 6.1. Introduction

This chapter applies to designing normal pavement structures for highway projects. Highway pavement structures are designed to withstand a specific number of standardized loadings derived from a known mix of truck-type traffic. Standardized vehicle loadings used in highway design are termed “equivalent single axle loads” (ESALs), i.e., the pavement structure will be subjected to a specific number of ESALs during its design life. This chapter describes how to calculate standardized ESAL loadings for your project. To facilitate the ESAL computation, planning personnel will provide you, the designer, with information concerning vehicle loadings as well as traffic growth rate and traffic lane distribution data. Similar concepts involving standardized vehicle loadings are used to calculate design aircraft loadings for aviation projects, although the methodology is not presented here.

Highway design designations provide information used for geometric and traffic design. The designer must obtain this information separately from planning.

With every application of an ESAL loading to the surface of a pavement structure, that structure receives a specifically quantifiable amount of structural damage. In other words, every ESAL application subtracts a finite amount from the pavement structure’s “life.” If the project involves construction of a new pavement structure or replacing an old one, one ESAL value will be needed for design, i.e., future ESALs (ESALs estimated for the design life of the new pavement structure). If the project involves placing an overlay on an existing pavement layer, two ESAL values will be required: (1) historical ESALs (ESALs accumulated on the existing pavement structure during its past service life), and (2) future ESALs.

For determining design ESALs, only various categories of truck-type vehicles are defined in terms of standard ESAL loadings. Only medium and large trucks are assigned ESAL equivalency for design purposes. Automobiles, pickup trucks, and other relatively small vehicles have such small ESAL loadings that they do negligible damage to the pavement structure. An old rule-of-thumb is that pavement structural damage done by the passage of a single large truck is equivalent to that done by about 9,000 automobiles.

**ESAL Defined:** One ESAL represents a single standardized load application. Each ESAL is known to cause a quantifiable and standardized amount of damage to the pavement structure equivalent to one pass of a single 18,000-pound, dual-tire axle with all four tires inflated to 110 psi.

**ESAL Truck Classification and Load Factor Defined:** Different sizes of truck are “pigeonholed” by size-category, known to DOT&PF as truck category. DOT&PF defines five truck categories (2-axle, 3-axle, 4-axle, 5-axle, and ≥6-axle). Trucks assigned to the 2-axle category have one front axle and one rear axle. Trucks assigned to the 3-axle category have one front axle and a tandem rear axle set. Trucks assigned to the 4-axle category are “semi” tractor/trailer combinations having one front axle on the tractor, a tandem set of driver axles on the tractor, and one axle at the rear of the trailer. Trucks assigned to categories higher than the 4-axle type are simply tractor/trailer or tractor/multi-trailer combinations having a total of two or more trailer axles.

Each of the five truck categories, according to scalehouse data, is assigned a specific ESAL equivalency. The assigned ESAL equivalency is termed the **load factor**—and every truck in that category is assigned that load factor. Assignment of a load factor to each truck category is specific to a particular scalehouse. Therefore, load factors generated at a particular scalehouse are valid only for those highway routes having truck load-weight characteristics similar to that scalehouse.

## 6.2. Calculate the Load Factor for Each Vehicle Category

This section provides a somewhat generalized description of how a load factor for each DOT&PF truck category is determined. Even though load factor data will be supplied to the designer, basic load factor computations are briefly discussed here to promote more thoroughly understanding of the concept of standardized loadings.

Load factor is defined as the average number of ESALs associated with each truck of a particular truck-size category. Load factors for all categories of truck size are usually calculated by regional planning sections and will be supplied to you when you request traffic data for your project. Planning provides load factor data on the truck classification table of the traffic data request form (see Figure 6-1). Load factors are necessary input data for the design ESAL calculations described in Section 6.3. One ESAL equivalent loading is defined for various axles or axle group configurations loaded as shown in Table 6-1.

**Table 6-1. Standard Load Equivalencies**

Type of Axle or Axle Group	Loading Equivalent to One ESAL (kips)
single tire single axle	12
dual tire axle	18
tandem axle group	32
tridem axle group	48
4 or more axle group	48

An axle is considered part of an axle group when it is less than 8 feet from another axle or group. For example, if two single axles are less than 8 feet apart, they are considered a tandem axle. If a single axle is less than 8 feet from a tandem axle, the three are considered a tridem axle.

Load factors are determined from scalehouse weight data obtained from many individual trucks. At the scalehouse, axle and axle group weights are sampled from a number of individual trucks representing each truck category. Each truck to be weighed is first assigned to a particular category. Then each axle and axle group (single, dual, tandem, etc.) for that truck is weighed individually. For each truck, an ESAL value is calculated for each axle and axle group (using the following ESAL equation).

The ESAL equation from truck axle weight and axle spacing for all axles or groups is:

$$ESAL = \left( \frac{W_1}{W_2} \right)^{4.3}$$

where:

$W_1$  = weight in kips of the loaded axle or axle group.

$W_2$  = weight in kips of the standard axle or axle group (see Table 6-1)

The total ESAL value, i.e., load factor, for that particular truck is the sum of ESAL values for all axles and axle groups of that truck.

The load factor for each truck category is determined by averaging the total ESAL values for all trucks in that category.

<b>Traffic Data Request Form</b>			TDR Form-1-10/20/03																		
Alaska Department of Transportation & Public Facilities																					
<b>Requested By:</b>		<b>Design Project Number:</b>	<b>Date Requested:</b>																		
<b>Base Year:</b> <b>Base Year Total AADT:</b> <b>AADT Growth Rate</b> <div style="display: flex; justify-content: space-between;"> <span><b>Forward (%/yr):</b></span> <span><b>End Year:</b></span> </div> <div style="display: flex; justify-content: space-between;"> <span><b>Back Cast (%/yr):</b></span> <span><b>Begin Year:</b></span> </div>		<b>Common Route Name:</b> <b>Functional Class:</b> <div style="text-align: center;"><b>Urban/Rural</b></div> <b>Historic M.P. Interval:</b>	<b>CDS Route Name:</b>  <b>CDS M.P. Interval:</b>																		
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 20%;">Truck Category</th> <th style="width: 20%;">Load Factor (ESALs per Truck)</th> <th style="width: 20%;">% of Total AADT in Truck Category</th> </tr> </thead> <tbody> <tr><td style="text-align: center;">2-axle</td><td></td><td></td></tr> <tr><td style="text-align: center;">3-axle</td><td></td><td></td></tr> <tr><td style="text-align: center;">4-axle</td><td></td><td></td></tr> <tr><td style="text-align: center;">5-axle</td><td></td><td></td></tr> <tr><td style="text-align: center;">≥ 6-axle</td><td></td><td></td></tr> </tbody> </table>		Truck Category	Load Factor (ESALs per Truck)	% of Total AADT in Truck Category	2-axle			3-axle			4-axle			5-axle			≥ 6-axle			<b>Lane Configuration Sketch:</b> (Designer: Provide sketch of lane layout. Number each lane and show directions.)	
Truck Category	Load Factor (ESALs per Truck)	% of Total AADT in Truck Category																			
2-axle																					
3-axle																					
4-axle																					
5-axle																					
≥ 6-axle																					
<b>Percent of Base Year Total AADT for Each Numbered Lane in Configuration Sketch:</b> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 20%;">Lane #</th> <th style="width: 20%;">%</th> </tr> </thead> <tbody> <tr><td>Lane #</td><td>%</td></tr> <tr><td>Lane #</td><td>%</td></tr> <tr><td>Lane #</td><td>%</td></tr> <tr><td>Lane #</td><td>%</td></tr> <tr><td>Lane #</td><td>%</td></tr> <tr><td>Lane #</td><td>%</td></tr> </tbody> </table>		Lane #	%	Lane #	%	Lane #	%	Lane #	%	Lane #	%	Lane #	%	Lane #	%	<b>Comments:</b>					
Lane #	%																				
Lane #	%																				
Lane #	%																				
Lane #	%																				
Lane #	%																				
Lane #	%																				
Lane #	%																				
<b>Data Provided By:</b>		<b>Provider's Signature:</b>	<b>Date Provided:</b>																		

**Figure 6-1. Traffic Data Request (TDR) Form**

### 6.3. Calculate Design ESALs

Estimate total ESALs for the design period by projecting forward the construction year ESALs for each truck category.

#### 6.3.1. Outline of Computation Steps

1. Obtain basic information from planning personnel. These data are based on studies of scalehouse data, weigh-in-motion data, traffic counts, administrative studies/projections, and miscellaneous observations.
  - AADTs for base year (both directions). Base year data is a best estimate of design data for a given design location and for a specific year—usually for the year that the project is being designed. Using compound growth calculations, a past year or future year, AADT may be calculated from the base year AADT. The base year must be identified by whoever supplies the AADT data.
  - Traffic growth rate (% per year) from base year
    - forward
    - backcast (if applicable for historical ESAL calculations)
  - Number of driving lanes
  - Directional split
    - Determine design lane as lane having highest portion of directional split
  - Load factor information for each truck category
  - Percent of AADT in each truck category

To facilitate collecting previously indicated data, submit the Traffic Data Request (TDR) Form (shown as Figure 6-1) to your regional planning section. You may need to submit more than one copy of Figure 6-1 for a particular project because large projects may require more than one pavement structural design. Exercise engineering judgment to determine if more than one pavement design is required for your project. In general, road segments within a project that are expected to have significantly different traffic volumes and/or vehicular mix may warrant separate pavement designs.

2. For the year of construction, determine number of ESALs in each truck category based on AADT of the design lane.
  - a. Calculate total AADT for year of construction using  $i_{B \text{ to } D}$  and “single payment” compound amount factor  $(1 + i_{B \text{ to } D})^n$ 
    - where:  $n$  = year of construction – base year
    - $i_{B \text{ to } D}$  = growth rate from base year to last year of design period
    - Construction year total AADT = (base year AADT)  $\times$  (compound amount factor)
    - (values for  $i$  and  $n$  are obtained from TDR form (see Figure 6-1))
  - b. Calculate construction year AADT in the design lane.
    - Construction year AADT in design lane = (construction year total AADT)  $\times$  (% AADT in design lane/100)
    - \* usually select highest % shown in TDR form (see Figure 6-1)

- c. For each truck category, calculate the construction year ESALs in the design lane. Use the following equation for each truck category.

$$\text{Construction year ESALs for specific truck category} = (\text{construction year AADT in design lane}) \times (\% \text{ of total AADT in truck category} / 100) \times (\text{load factor for truck category}) \times 365$$

\* obtained from TDR form (see Figure 6-1)

- d. Calculate the total of construction year ESALs for all truck categories.

$$\text{Total construction year ESALs} = \Sigma \text{ construction year ESALs for every truck category}$$

3. Calculate total number of ESALs for each truck category accumulated from the year of construction through the end of the design period.

- a. Calculate total ESALs for design. Project total construction year ESALs for all truck categories (calculated in step 2d) forward to end of design period using  $i_{B \text{ to } D}$  and “uniform series,” compound amount factor  $\left[ (1 + i_{B \text{ to } D})^n - 1 \right] / i_{B \text{ to } D}$

where:  $n$  = last year of design period – construction year

$$\text{Total design ESALs} = (\text{total construction year ESALs}) \times (\text{compound amount factor})$$

(values for  $i$  and  $n$  are obtained from TDR form (see Figure 6-1))

### 6.3.2. An Example (Calculate Design ESALs Forward in Time)

#### Input Data:

The project will be constructed in 2005 and has a 15-year design life (end year of design period = 2020).

Design work was done in 2003, the base year chosen for estimating the AADT growth rate.

For this example, Figure 6-2 shows an example of basic traffic data obtained, on TDR form (see Figure 6-1), from the regional planning section.

#### Calculations:

Design ESAL computations for this example follow the Section 6.3.1 outline.

#### Step 1

Already completed with the collection of the indicated input data (use Figure 6-2).

#### Step 2

- a. Construction year total AADT = (base year total AADT)  $\times (1 + i_{B \text{ to } D})^n = (1600) \times (1 + 0.025)^2 = 1,681$
- b. Construction year AADT in design lane = (construction year total AADT)  $\times (\% \text{ AADT in design lane} / 100) = (1681) \times (0.6) = 1,009$
- c. Construction year ESALs for specific truck category = (construction year AADT in design lane)  $\times (\% \text{ of total AADT in truck category} / 100) \times (\text{load factor for truck category}) \times 365$

See rows of computations in Table 6-2.

- d. Total construction year ESALs =  $\Sigma$  of construction year ESALs for all truck categories =  $3,683 + 12,522 + 17,678 + 17,125 + 8,250 = 59,258$

See summation in Table 6-2.

<b>Traffic Data Request Form</b> Alaska Department of Transportation & Public Facilities			TDR Form-1-10/2003																		
<b>Requested By:</b> R.L. Jones, Northern Region Design Section		<b>Design Project Number:</b> AK-33502-(2)A	<b>Date Requested:</b> May 18, 2003																		
<b>Base Year:</b> 2003  <b>Base Year Total AADT:</b> 1,600  <b>AADT Growth Rate</b> Forward (%/yr): 2.5 <b>End Year:</b> 2020  Backcast (%/yr): 1.6 <b>Begin Year:</b> 1990		<b>Common Route Name:</b> Stanley Road <b>Functional Class:</b> Urban/Rural	<b>CDS Route Name:</b> Jones/Stanley Road (CDS 1122055)  <b>CDS M.P. Interval:</b> 7.25 to 9.75																		
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 20%;">Truck Category</th> <th style="width: 20%;">Load Factor (ESALs per Truck)</th> <th style="width: 20%;">Percent of Total AADT in Truck Category</th> </tr> </thead> <tbody> <tr><td>2-axle</td><td>0.50</td><td>2</td></tr> <tr><td>3-axle</td><td>0.85</td><td>4</td></tr> <tr><td>4-axle</td><td>1.20</td><td>4</td></tr> <tr><td>5-axle</td><td>1.55</td><td>3</td></tr> <tr><td>≥ 6-axle</td><td>2.24</td><td>1</td></tr> </tbody> </table>		Truck Category	Load Factor (ESALs per Truck)	Percent of Total AADT in Truck Category	2-axle	0.50	2	3-axle	0.85	4	4-axle	1.20	4	5-axle	1.55	3	≥ 6-axle	2.24	1	<b>Lane Configuration Sketch:</b> (Designer: Provide sketch of lane layout. Number each lane and show directions.)  	
Truck Category	Load Factor (ESALs per Truck)	Percent of Total AADT in Truck Category																			
2-axle	0.50	2																			
3-axle	0.85	4																			
4-axle	1.20	4																			
5-axle	1.55	3																			
≥ 6-axle	2.24	1																			
<b>Percent of Base Year Total AADT for Each Numbered Lane in Configuration Sketch:</b> <table border="1" style="width: 100%; border-collapse: collapse;"> <tbody> <tr> <td style="width: 30%;">Lane # 1</td> <td style="width: 30%;">%</td> <td style="width: 40%;">60 (50 historic)</td> </tr> <tr> <td>Lane # 2</td> <td>%</td> <td>40 (50 historic)</td> </tr> <tr> <td>Lane #</td> <td>%</td> <td></td> </tr> <tr> <td>Lane #</td> <td>%</td> <td></td> </tr> <tr> <td>Lane #</td> <td>%</td> <td></td> </tr> <tr> <td>Lane #</td> <td>%</td> <td></td> </tr> </tbody> </table>		Lane # 1	%	60 (50 historic)	Lane # 2	%	40 (50 historic)	Lane #	%		Lane #	%		Lane #	%		Lane #	%		<b>Comments:</b> Note that I am requesting you supply both future and historic traffic data.  	
Lane # 1	%	60 (50 historic)																			
Lane # 2	%	40 (50 historic)																			
Lane #	%																				
Lane #	%																				
Lane #	%																				
Lane #	%																				
<b>Data Provided By:</b> J.J. Sandler, N. Region Planning		<b>Provider's Signature:</b> 	<b>Date Provided:</b> June 14, 2003																		

Figure 6.2. Completed Traffic Data Request (TDR) Form for Examples

**Table 6-2. Construction Year ESAL Calculations**

Truck Category	(1) Construction Year Design Lane AADT	(2) % of Total AADT in Truck Category	(3) Load Factor for Truck Category	(1) × (2) × (3) × 3.65 Construction Year ESAL
2-axle	1009	2	0.50	3,683
3-axle	1009	4	0.85	12,522
4-axle	1009	4	1.20	17,678
5-axle	1009	3	1.55	17,125
≥6-axle	1009	1	2.24	8,250
Total construction year ESALs =				59,258

**Step 3**

$$\text{Total design ESALs} = (\text{total construction year ESALs}) \times \left[ \frac{(1 + i_{B \text{ to } D})^n - 1}{i_{B \text{ to } D}} \right]$$

$$= (59,258) \times \left[ \frac{(1 + 0.025)^{15} - 1}{0.025} \right] = 1,062,610 \text{ Total design ESALs}$$

**6.4. Historical ESALs**

For rehabilitation projects, the historical ESALs are required for the analysis of the remaining pavement life. If historical AADTs exist for each year since the last pavement construction project, calculate ESALs for each year to the present—using methods in Section 6.3. The total historical ESAL is the sum of the past yearly ESALs. If load factors for past years are not available, use base year (present) load factors, and perhaps adjust based on careful consideration and judgment. Past growth rate information must be obtained from planning personnel. Request that historical traffic data be added to the TDR form (see Figure 6-1) if historical ESALs need to be calculated. After obtaining the historical growth rate from planning and collecting or estimating the other input data, calculate historical ESALs using the same steps outlined in Section 6.3.1.

**6.4.1. An Example (ESAL Calculation Extended Backwards and Based on Previous Example)**  
**Input Data**

Input data for calculating historical ESALs are similar to those used for calculating future ESALs (see Section 6.3.2 example) except that data come from the construction year and years prior to that time.

The project will be constructed in 2005 and the backward (backcast) projection of ESALs will extend to the previous surfacing application in 1990, i.e., the historical construction year.

Use data pertaining to historical ESAL calculations from the TDR form used in the previous example (see Figure 6-2).

Construction work will be done in 2005. This now becomes the “base” year for estimating the AADT in 1990.

AADT for (2005) = 1,681 (from previous example)

Figure 6-2 shows that the traffic growth rate from the last historical construction event (1990) to the original base year (2003) of design period was 1.6% (this historical growth rate is identified as  $i_{H \text{ to } C}$ )

Load factors and percent of AADT in each truck category are shown in Figure 6-2. Notice that these are the same data used in the previous example for projecting ESALs into the future (a simplification for this example). For historical ESAL projections, use actual historical truck category data if they are available. If available, planning would include historical truck category data, as separate numbers, to the “truck related table” of the TDR form.

## Calculations

Historical ESAL computations generally follow the method outlined in Section 6.3.1.

### Step 1

Already completed with the collection of the indicated input data (use Figure 6-2).

### Step 2

$$\text{a. Historical construction year total AADT} = (\text{construction year AADT}) \times \frac{1}{(1 + i_{H \text{ to } C})^n} \\ = (1681)/(1+0.016)^{15} = 1,325$$

where:  $i_{H \text{ to } C} = 0.016$

$n = \text{construction year} - \text{historical construction year} = 2005 - 1990 = 15$

$$\text{b. Historical construction year AADT in design lane} = (\text{historical construction year total AADT}) \times (\text{historical \% of total AADT in truck lane}/100) = (1325) \times (0.5) = 663$$

$$\text{c. Historical construction year ESALs for specific truck category} = (\text{historical construction year AADT in design lane}) \times (\text{historical \% of total AADT in truck category}/100) \times (\text{historic load factor for truck category}) \times 365$$

See rows of computations in Table 6-3.

$$\text{d. Total construction year ESALs} = \Sigma \text{ of construction year ESALs for all truck categories} \\ = 2,420 + 8,228 + 11,616 + 11,253 + 5,421 = 38,938$$

See summation in Table 6-3.

**Table 6-3. Historical Construction Year ESAL Calculations**

Truck Category	(1) Historical Construction Year Design Lane AADT	(2) % of Total AADT in Truck Category	(3) Load Factor for Truck Category	(1) × (2) × (3) × 3.65 Historical Construction Year ESAL
2-axle	663	2	0.50	2,420
3-axle	663	4	0.85	8,228
4-axle	663	4	1.20	11,616
5-axle	663	3	1.55	11,253
≥6-axle	663	1	2.24	5,421
Total historical construction year ESALs				= 38,938

### Step 3

$$\text{Total historical ESALs} = (\text{total historical construction year ESALs}) \times \left[ \frac{(1 + i_{H \text{ to } C})^n - 1}{i_{H \text{ to } C}} \right]$$

$$= (38,938) \times \left[ \frac{(1 + 0.016)^{15} - 1}{0.016} \right] = 654,247 \text{ Total historical ESALs.}$$